Modeling Electrode Joints in Bending

by

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Introduction

Bending failures of electrode columns during scrap caves are a recurring problem in electric arc furnace steel making. The Electrode Systems Division has developed a room temperature cantilever beam test of an assembled column for the evaluation of the resistance of joints to these high column failures. A finite element model of this test has recently been developed. Previous finite element models of the column and joint[1-6] have dealt with axisymmetric mechanical or thermal stresses. The symmetry of these stresses results in considerable savings in computation. The model below is the first reported effort to deal with the three-dimensional problem posed by the transverse loading of an otherwise axisymmetric column.

Experiment

A full column, of 20-inch or 24-inch diameter electrodes, is assembled and clamped in a holder. A hydraulic system is used to apply a known force to a point near the end of the column, 17 feet from the bottom of the holder and approximately 16 feet below the end faces of the test joint. Meaurements consist of the deflection of the tip of the column and of the strains at various points in the joint as functions of the bending moment. These measurements are continued until the test joint fails in bending. The strain gauges in the joint area are typically mounted on the tensile and compressive sides of the pin at its major diameter and on the socket walls at the first active thread from the bottom of the socket. These gauges are mounted at the bottom of slots cut approximately 1/8-inch below the roots of the threads. The assembled column and the strain gauges are pretested by loading in bending to approximately 50% of the expected failure moment.

Finite Element Model

A finite element model of the full length of the test column was developed using 3-D brick elements. The column axis and the direction of application of the bending load define a plane of symmetry for the bent column. This symmetry allowed the model to be reduced to that of a half-cylindrical column. Linear material stress-strain behavior was assumed, for convenience, in both the electrode and the pin. This assumption should be acceptable for loads up to one-half of the total failure load due to the prestressing to this level after column assembly. The material was assumed to be transversely isotropic with the symmetry plane in the against-grain direction. The five resulting elastic constants for the electrodes and pins were taken from measurements of longitudinal and shear moduli and Poisson's ratios.

A three-dimensional finite element model which included the geometric form of the threads would have required prohibitively large computing times and was, therefore, not attempted. Instead, point-to-point gap elements were used to represent the load transfer characteristics of both the thread flanks and the electrode end faces. These gap elements may have their initial gap separation, in inches, specified as either negative or positive. Positive openings correspond to true separations while negative initial openings represent an interference situation and trigger an automatic inteference fit procedure in the program. The ability to specify different gap openings for different "threads" has been used to model differences in taper between pin and electrode. The ability to force an interference fit has been used to simulate joint tightening. Friction on the thread flanks and end faces could have been included, but was neglected for the results below. Neglect of thread root geometry means that calculated strains will differ from measured strains. This difference is expected to be minimal at the pin major diameter. The machining of the joint precludes thread contact exactly at the major diameter. In addition, the strain gauge is mounted a small distance below the roots of these disengaged threads. The stress concentration of the roots of the engaged threads near the base of the socket (BOS) cannot be ignored. The assumption will be made, however, that this concentration effect is effectively independent of the larger scale aspects of joint design and that comparisons among joints of different designs are valid even when the exact magnitude of the stresses is in doubt.

Results

The strains predicted by the finite element model will be compared with experimental data from two very different joints: a standard size, standard taper, standard material joint and a large pin, high taper joint with an electrode grade pin. This latter joint was taken as representative of the design covered by a patent[7] which claims reduced stresses in the base-of-socket (BOS) area.

Figure 1 shows the experimental and predicted strains on the tensile and compressive sides of the pin major diameter for the standard joint. The tensile strain is predicted satisfactorily up to approximately one-half the failure moment, at which point nonlinearity begins to become important. The behavior of the compressive strain is dominated by the separation of the electrode end faces and the movement of the pin within the socket. The resultant strain is small and shows an indication of becoming tensile. The model does an excellent job of representing the major effects of this behavior. Figure 2 shows the strains at the major diameter of the large, high taper pin. After an initial "seating" of the joint, the model and experimental tensile strains are substantially identical. The model also does a satisfactory job of accounting for the small compressive strain which, in this joint, shows no sign of becoming tensile.

Figure 3 shows the strains at the BOS for both of the test joints. The average of upper and lower socket BOS strains is used for both the experimental and calculated results. The experimental strain is greater than that calculated by the model, as expected from thread root stress concentration. The large, high taper joint does show the reduction in BOS strain as taught by the Seldin-Weng patent.[7] Both the experimental data and finite element results confirm this reduction.

Discussion

The finite element model has been found to work well in accounting for the bending strains in the pin including the essential similarity of strains in two very different pin designs and materials. The model does not, due to its neglect of thread-root geometry, give accurate prediction of the magnitudes of the peak strains at the BOS. However, the trend of BOS nominal strain with joint design, as evidenced by the different strain levels in normal and high taper joints, is well described by the model. The model can, therefore, be used to study the influence of joint design on high column performance.

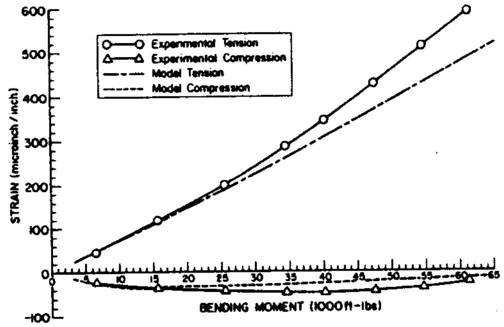

Figure 1: Bending Strains at the Major Diameter of a Standard Pin.

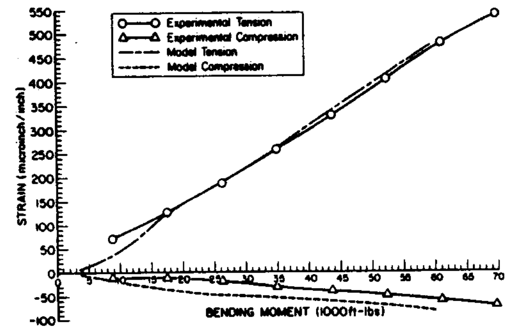

Figure 2: Bending Strains at the Major Diameter of a Large, High Taper Pin.

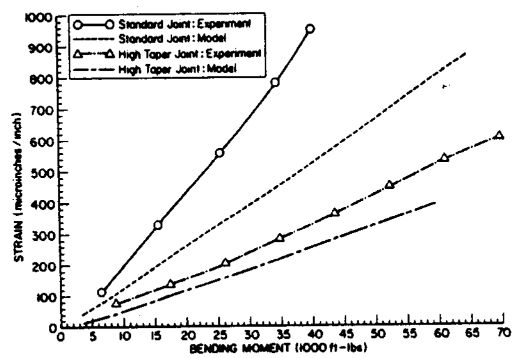

Figure 3: Bending Strains in the BOS Region of Standard and High Taper Joints.

Reference

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